TR-91-08

(2)

AD-A241 205

Grant AFOSR-87-0378

TOTAL ELECTRON CONTENT AND SCINTILLATION IN THE VICINITY OF THE MAIN IONOSPHERIC TROUGH OVER NORTHERN EUROPE

L.KERSLEY
I.K.WALKER

Department of Physics
University College of Wales
Aberystwyth, U.K.

30 June 1991

Final Scientific Report

Prepared for

European Office of Aerospace Research and Development,
223/231 Old Marylebone Road,
London NW1 5TH.

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release;
distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
AFOSR-87-0378

5. MONITORING ORGANIZATION REPORT NUMBER(S)
TR-91-08

6a. NAME OF PERFORMING ORGANIZATION
University College of Wales

6b. OFFICE SYMBOL *(If applicable)*

7a. NAME OF MONITORING ORGANIZATION
European Office of Aerospace
Research and Development

6c. ADDRESS *(City, State, and ZIP Code)*
Department of Physics
Penglais,
Aberystwyth, Dyfed SY23 3BZ, U.K.

7b. ADDRESS *(City, State, and ZIP Code)*
EOARD
PSC 802 Box 14
FPO AE 09499-0200

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
EOARD

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
AFOSR-87-0378

8c. ADDRESS *(City, State, and ZIP Code)*
223/231 Old Marylebone Road,
LONDON NW1 5TH, U.K.

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
Total Electron Content and Scintillation in the Vicinity of the Main Ionospheric Trough over Northern Europe.

12. PERSONAL AUTHOR(S)
L. Kersley and I.K. Walker

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final scientific	FROM 90.7.1 TO 91.6.30	91.6.30	25

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Total electron content, ionospheric trough, ionospheric irregularities, scintillation boundary.

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*
A receiving system for NNSS satellites located at Lerwick (60.1N, 1.2W) has been used to make differential carrier phase measurements in the vicinity of the main ionospheric trough. The observations have been calibrated to obtain absolute total electron content using measurements from a co-located GPS receiver for two months near solar maximum. Mapping techniques, developed to study the changes in night-time total electron content as a function of both latitude and time, are described. Examples are given of characteristic trough behaviour for different levels of geomagnetic activity. A new feature of the work is the limited extent of the poleward wall of the trough for moderate geomagnetic conditions. The mapping techniques can also be applied to measurements of radio-wave scintillation allowing comparison between small-scale irregularity behaviour and the larger-scale changes in total electron content. An example is discussed where there is a close association of scintillation occurrence with a northward gradient in electron content, illustrating the potential of the techniques to the investigation of the small-scale irregularities responsible for scintillation.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE *(Include Area Code)*

22c. OFFICE SYMBOL

TR-91-08

This report has been reviewed and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Owen Coté

OWEN R. COTE'
Chief, Geophysics and Space

Ronald J. Lisowski

RON LISOWSKI, Lt Col, USAF
Chief Scientist

INTRODUCTION

The project is concerned with the monitoring of ionospheric total electron content (TEC) and radio-wave scintillation in the vicinity of the main ionospheric trough over northern Europe. A receiving system based at Lerwick in the Shetland Islands (60.1°N 1.2°W) is being used to record signals on 150 MHz and 400 MHz transmitted from the constellation of the Navy Navigational Satellite System (NNSS). The variation of total electron content as a function of latitude is determined from the differential carrier phase of the recorded signals. Details of the experimental arrangement and some preliminary results have been given in an earlier report by Kersley et al. (1990)[1].

In the current report a brief description is given of the background to studies of the midlatitude ionospheric trough and the scintillation boundary. This is followed by a summary of the NNSS observations at Lerwick and the techniques used to obtain absolute total electron content measurements. Analysis procedures used to construct maps of morphological variations of total electron content and scintillation are then described and results presented and discussed illustrating aspects of trough and scintillation behaviour for selected observations around the maximum of the solar cycle.

BACKGROUND - THE MIDLATITUDE TROUGH AND SCINTILLATION BOUNDARY

The midlatitude ionospheric trough has been the subject of considerable study since its discovery in the mid 1960's. A review by Wrenn and Raitt (1975)[2] details the early work, while more recent studies have been summarised by Moffett and Quegan (1983)[3]. Rodger et al. (1986)[4] noted that many studies, especially those carried out using satellite data, concentrate on the location of the trough minimum as this is usually the most readily identifiab'e feature in the data.

1. Kersley L., Walker I.K. and Russell C.D. Total electron content in the vicinity of the main trough over northern Europe. Report AFOSR-87-0378, University College of Wales, June 1990.

2. Wrenn G.L. and Raitt W.J., Annls. geophys. 31, 17, 1975.

3. Moffett R.J. and Quegan S., J. Atmos. Terr. Phys., 45, 315, 1983.

4. Rodger A.S., Brace L.H., Hoegy W.R. and Winningham J.D., J. Atmos. Terr. Phys., 48, 715, 1986.

A-1

Little information is available about gradients in the vicinity of the minimum, though it seems generally accepted that the poleward wall of the trough is steeper than that on the equatorial side of the depression.

The scintillation boundary is the name given to the sharp equatorward edge of a region of scintillation producing irregularities encompassing the auroral zone. Studies of the boundary have been carried out by several workers in both the northern and southern hemispheres. Early work involved basic occurrence morphology including diurnal behaviour, response to geomagnetic activity and relationship to or independence from the ionospheric trough (see references 5 to 11). While many of the early observations were made using low vhf transmissions, Wand and Evans (1975)[12] reported measurements of amplitude scintillations at 150 MHz made at Millstone Hill, USA, using NNSS satellites. Their study showed an equatorward motion of the scintillation boundary in response to magnetic activity, the motion being especially marked in the midnight sector in winter and in the early morning sector in summer.

Early attempts to investigate the relationship between the trough and scintillation boundary suggested that the two phenomena had statistical behaviours that were broadly similar. However,

---

5. Beynon W.J.G. and Jones E.S.O The scintillation of radio signals for the Discoverer 36 satellite. J. Atmos. Terr. Phys., 26, 1175, 1964.

6. Aarons J., Mullen J.P. and Whitney H.E. The scintillation boundary. J. Geophys. Res., 69, 1785, 1969.

7. Aarons J. and Allen R.S. Scintillation boundary during quiet and disturbed magnetic conditions. J. Geophys. Res., 76, 170, 1971.

8. Oksman J. and Tauriainen A. On annual movements of the scintillation boundary of satellite signals. J. Atmos. Terr. Phys., 33, 1727, 1971.

9. Stuart G.F. Characteristics of the abrupt scintillation boundary. J. Atmos. Terr. Phys., 34, 1455, 1972.

10. Kersley L., Jenkins D.B. and Edwards K.J. Relative movements of midlatitude trough and scintillation boundary. Nature Phys. Sci., 239, 11, 1972.

11. Kersley L., van Eyken A.P. and Edwards K.J. ionospheric mid-latitude trough and the abrupt scintillation boundary. Nature, 254, 312, 1975.

12. Wand R.H. and Evans J.V. Morphology of ionospheric scintillation in the auroral zone. I.E.S.75, NTIS CSCL 04/1 N75-30714, NRL, Washington D.C., 1975.

Kersley et al. (1975)[11] concluded from simultaneous observations that the two features were essentially independent, having a relative motion that followed a diurnal pattern.

The current work is aimed at exploiting the abundance of suitable passes of NNSS satellites to gain further understanding of the characteristics of the trough as seen in total electron content and the scintillation boundary over northern Europe.

NNSS OBSERVATIONS

The automated receiving system for the current project, suitably modified to obtain differential carrier phase measurements, was established in Lerwick in 1989. To date some 12710 NNSS passes have been monitored. On average approximately 14 passes per day were recorded with an average time between passes of about 100 minutes, a key feature of the data base available for the current study. Selection criteria were used that required signals recorded from a pass to have a duration in excess of 10 minutes and to correspond to pass geometries giving ionospheric longitudes (at 350 km altitude) within ± 20 degrees of Lerwick. Using these criteria some 6222 passes have been analysed to provide the initial data base for the current study.

ABSOLUTE TOTAL ELECTRON CONTENT

The use of differential carrier phase measurements to obtain the latitudinal variation of equivalent vertical total electron content from a single satellite pass is well established. The analysis technique involves the assumption of a linear gradient in electron content in the vicinity of the point of satellite closest approach to estimate the absolute phase difference and hence the absolute electron content. Near the minimum of the ionospheric trough this assumption is open to question and the resulting estimates of the variations of electron content with latitude must be treated with extreme caution. The necessity for an independent calibration technique for the NNSS total electron content measurements has been discussed in an earlier report by Kersley et al. (1990)[1]. It was found that calibration was best achieved using independent measurements of absolute electron content from a receiving system operated by the Geophysics Laboratory, also located at the Lerwick observatory to monitor signals from satellites in the Global Positioning System (GPS). Where GPS results were not available a different calibration technique was discussed. Estimates of ionospheric slab thickness calculated from an empirical model (Kersley 1980)[13] were combined with values of maximum electron density obtained from observations of foF2 to yield total electron content. It should be noted that the ionosonde used was located at South Uist (57.4°N,4.05°W) and the foF2 measurements were obtained from the online database held at the World Data Centre (RAL UK). During the period under review measurements at South Uist were discontinued as part of a programme to relocate the ionosonde at Lerwick. Whilst foF2 measurements made at Lerwick will undoubtedly benefit the current experiment, the change in location has meant that no foF2 measurements are available since mid-July 1990. If the NNSS measurements made during this period, currently held in the form of variations of provisional relative total electron content, are to be calibrated, then it is essential that GPS results are made available.

To date, GPS measurements of absolute electron content have only been received for the periods 15 September to 21 October 1989 and 1 to 31 December 1989. The analysis of the NNSS observations and study of the results presented here has consequently been concentrated on these two months.

MAPPING TOTAL ELECTRON CONTENT

Measurements of differential carrier phase from NNSS satellite passes have been analysed to give the variation of total electron content as a function of latitude for each pass. Fig.1 shows examples of the resulting variation of equivalent vertical total electron content with latitude for observations from four consecutive passes between approximately 1750 UT and 2130 UT on the 4 October 1989. A trough-like profile is clearly seen in the observations commencing at 1918 UT and is again in evidence in the observations commencing at 2128 UT. In both cases there are steep gradients in the variation of total electron content with latitude on either side of the trough minimum. It can be noted that the position of the trough minimum descends in latitude with time from about 66°N in the observations commencing at 1918 UT to about 63°N in the observations commencing 2128 UT. The poleward wall of the trough is not apparent in the observations of

---

13. Kersley L. An empirical model of ionospheric slab thickness. AGARD CPP-284, 231, 1980.

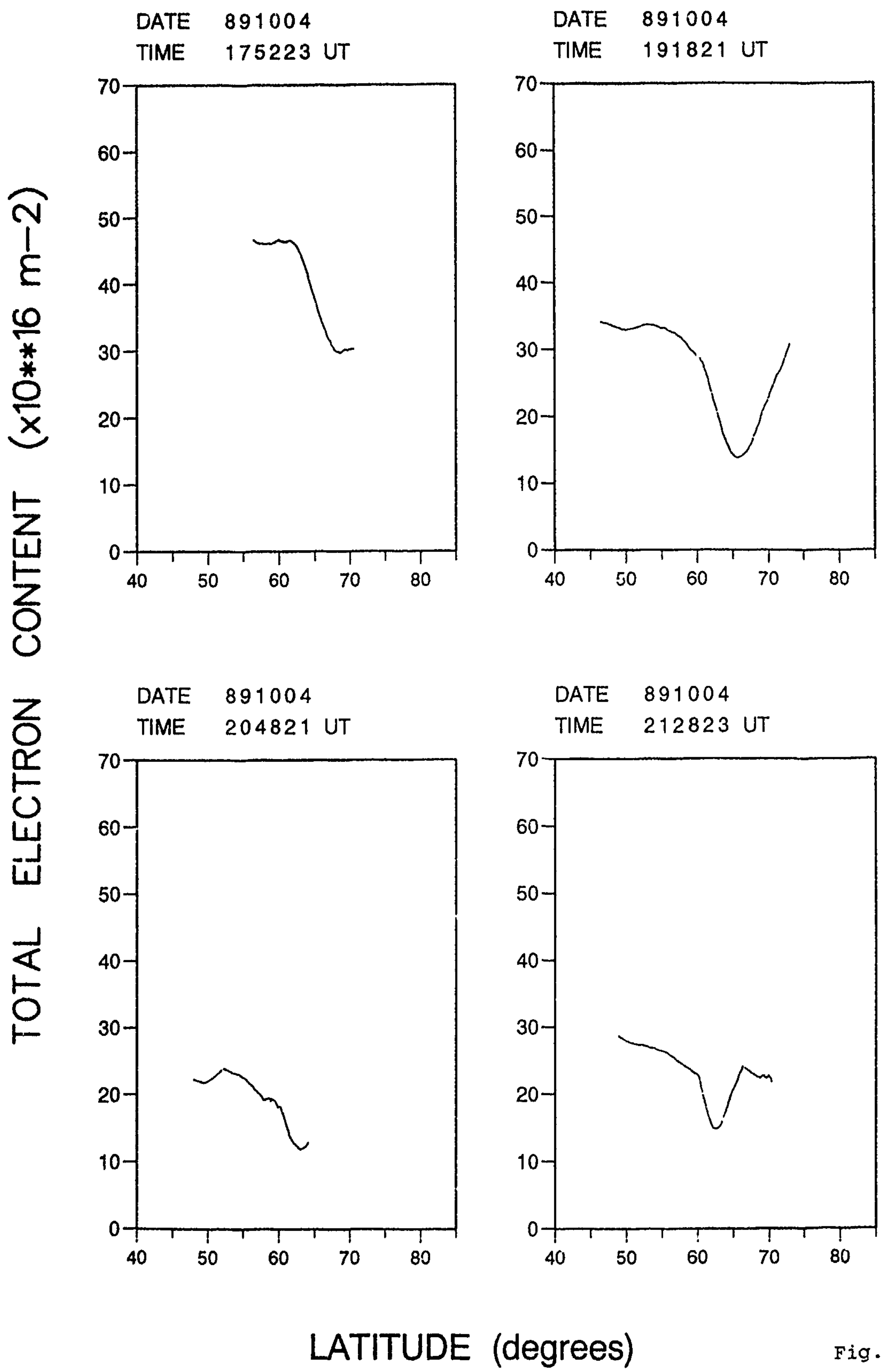
DATE 891004
TIME 175223 UT
DATE 891004
TIME 191821 UT
DATE 891004
TIME 204821 UT
DATE 891004
TIME 212823 UT
TOTAL ELECTRON CONTENT (x10**16 m-2)
LATITUDE (degrees)
0
10
20
30
40
50
60
70
40
50
60
70
80

Fig.1

the other two passes, however it would appear that the trough minimum was observed in each case at latitudes following a consistent pattern.

Extended sequences of satellite passes of this kind make it possible to combine observations from a number of successive passes to obtain variations not only in the spatial (latitudinal) dimension but also as a function of time. The resulting maps illustrate the changes in the variation of total electron content over some 25° of latitude as a function of time. Graphical procedures have been developed to display the observations as an aid to understanding the morphological behaviour of the trough region. For this purpose total electron content measurements were binned according to hour and latitude and then averaged to produce a value for each degree of latitude by one hour bin. The UNIRAS© interactive on-screen graphical processing allows appropriate selections to be made of the parameter ranges while exercising caution to ensure the integrity of the final output. An example of the full colour output available is given in Fig.2, though subsequent plots in this report are in black and white with suitable grey-scale contouring. Suitable examples have been chosen to illustrate aspects of trough behaviour from the available data within the two month periods listed.

TOTAL ELECTRON CONTENT AND THE TROUGH

An example of a contour map showing the variation of total electron content with latitude and time is shown in three-dimensional form in Fig.2. These data were obtained during the early evening and night of the 11-12 October 1989 and a total of 8 successive passes have been combined to produce the map. The most striking features are the decay in electron content with the progression from late evening into the night and the presence of the trough-like feature. The trough can be seen starting to develop as early as 1700 UT with a minimum around 70°N ionospheric geographic (IGG) latitude, and is clearly in evidence by 1800 UT. The position of the trough minimum descends in latitude with time, reaching about 64°N at 2300 UT. Steep gradients in both walls of the trough are apparent at this time, the steeper on the poleward slope. In this example, the trough is not so clearly defined in the post-midnight sector, with the equatorward wall becoming merged in the generally decaying night-time ionosphere particularly at lower latitudes. Geomagnetic conditions were quiet during this time, with Kp

11-12 OCT 1989

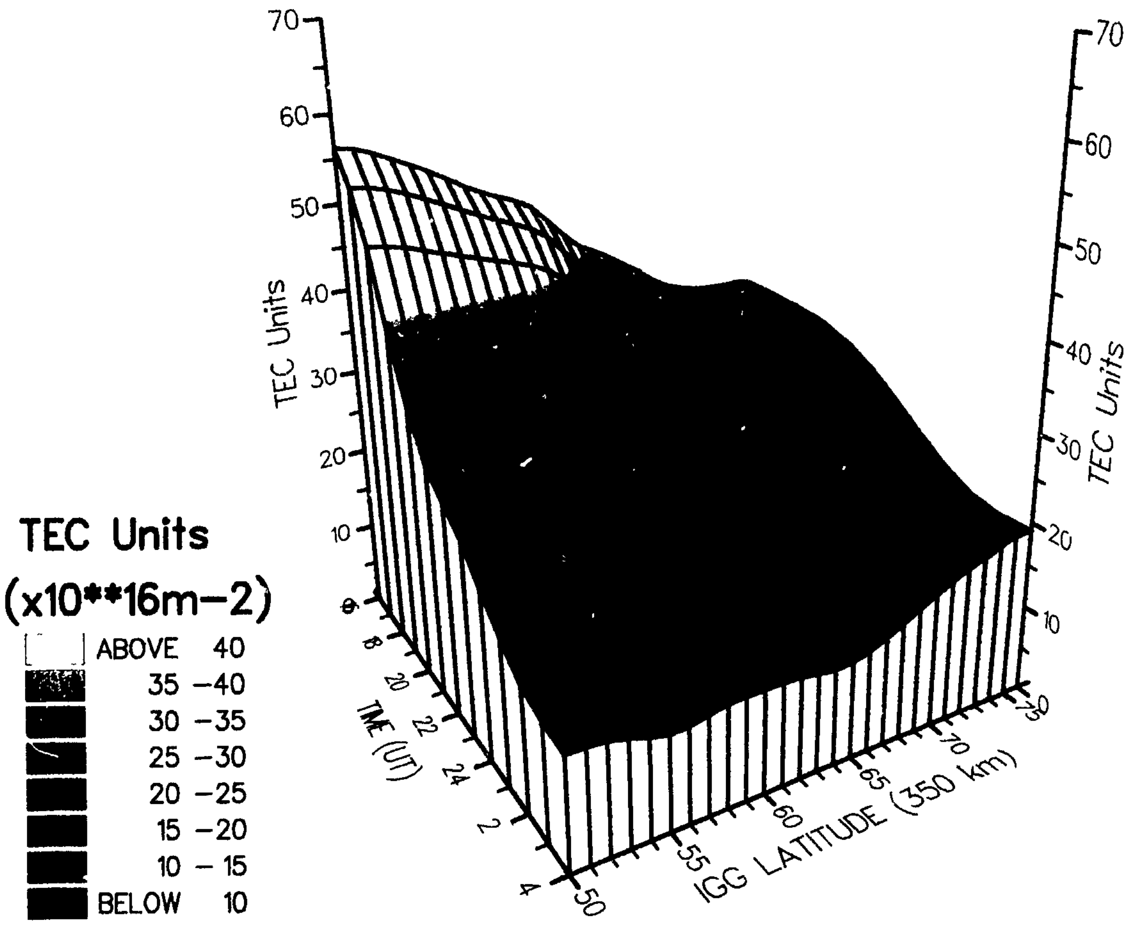

Fig.2

never exceeding 2-.

Fig.3 is another example of a total electron content map with a trough-like feature present. These data were obtained during the early evening and night of the 4-5 October 1989. For the purposes of comparison the grey-scales chosen are identical in this and subsequent plots used in this report. Once again total electron content is seen to decrease with the passage of time from evening into the night. The trough can be seen at about 71°N at 1700 UT, and it is well developed by 1900 UT. Steep gradients in electron content are evident on both walls of the trough and the position of the trough minimum is observed to descend in latitude with time reaching about 58°N by 0400 UT. After midnight it is clear that the poleward wall does not extend to much higher latitudes than about 63°N, the region further north being characterised by another broad minimum in electron content. This feature of a limited extent of the poleward wall of the trough has been found to be characteristic of the results for moderate levels of geomagnetic activity.

MONTHLY AVERAGE TOTAL ELECTRON CONTENT

The available GPS results effectively covered the months of October and December 1989. (It should be noted that for the purposes of what follows, "October" refers to the period 21 September to 21 October.) The same procedures outlined earlier to produce maps of total electron content were applied to all of the NNSS data for each month. The resulting map for October is shown in Fig.4. It should be noted that the appropriate time and latitude ranges have been chosen to remain consistent with the other total electron content maps presented. Some 490 NNSS satellite passes were used to produce this map. Once again it can be seen that there is a decrease in total electron content with time, from early evening into the night. A trough-like feature is present, though less clearly defined due to the effect of averaging. The minimum is about 73°N at 1600 UT with the lowest average total electron content being found around 0300 UT at about 58°N.

The corresponding average map for December is shown in Fig.5. This is characterised by generally lower values of total electron content and a trough motion that is rapidly equatorward before 2100 UT.

4-5 OCT 1989

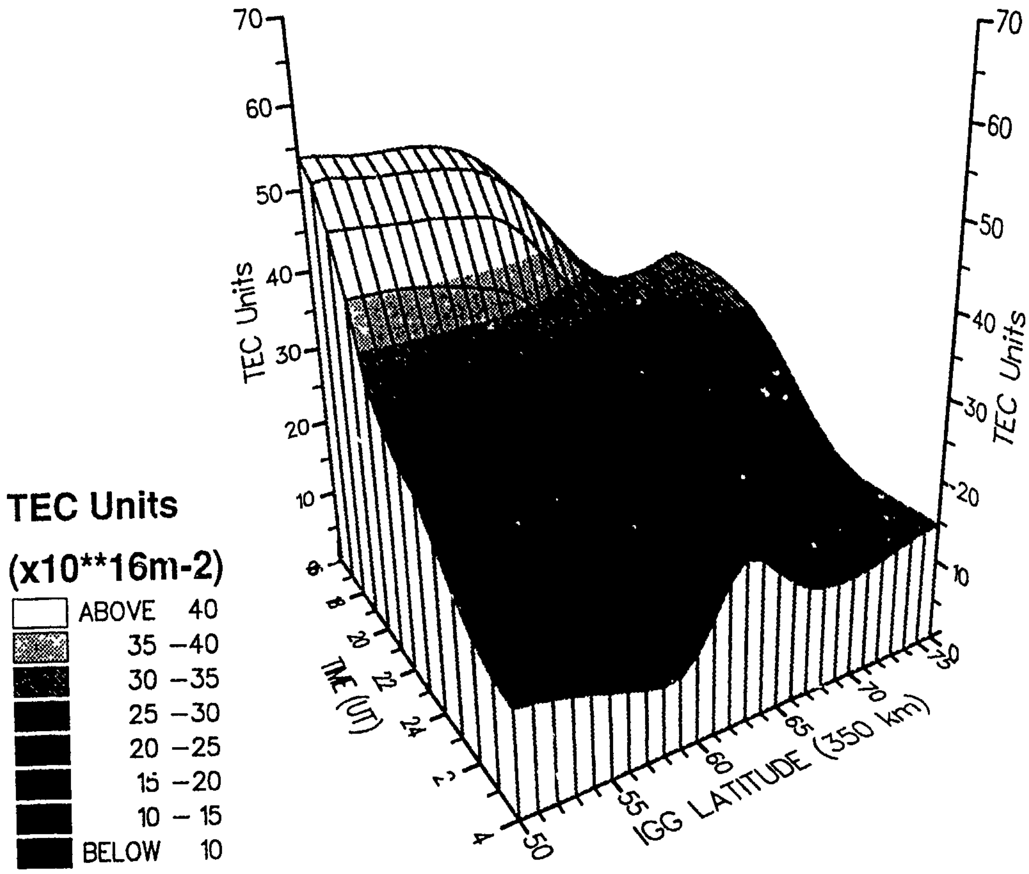

Fig.3

MONTH AVERAGE: OCTOBER 1989

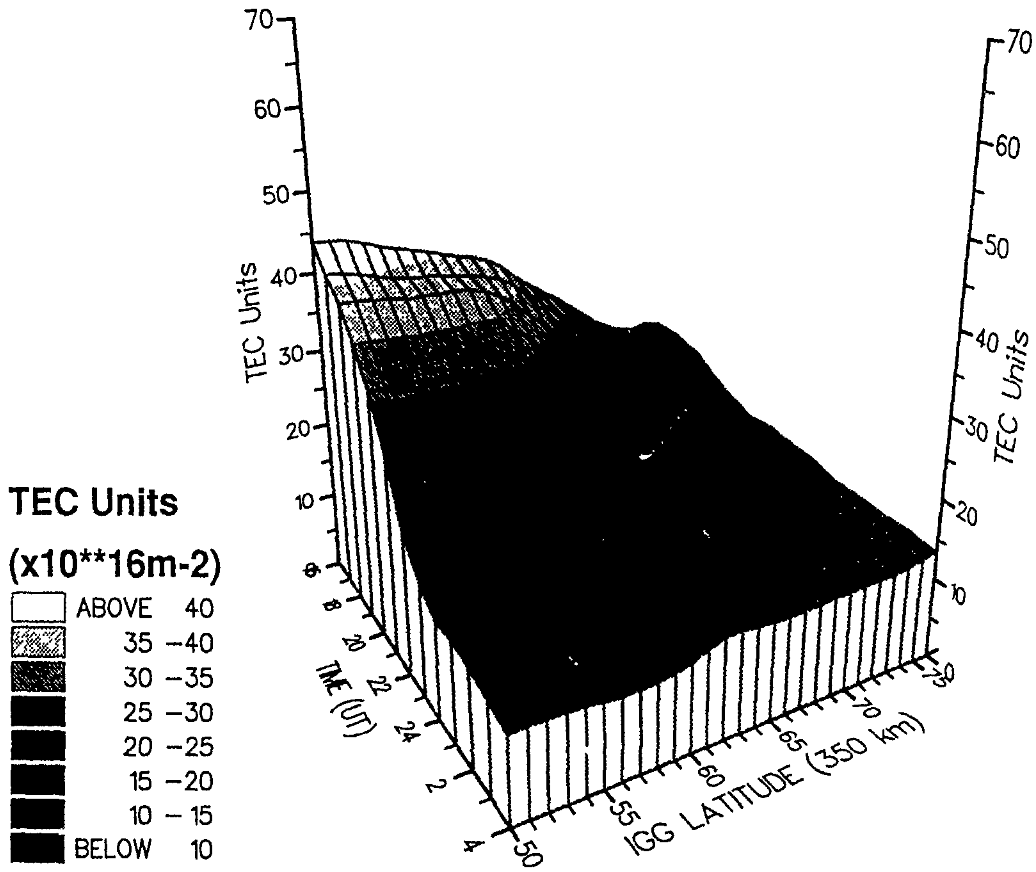

Fig.4

MONTH AVERAGE: DECEMBER 1989

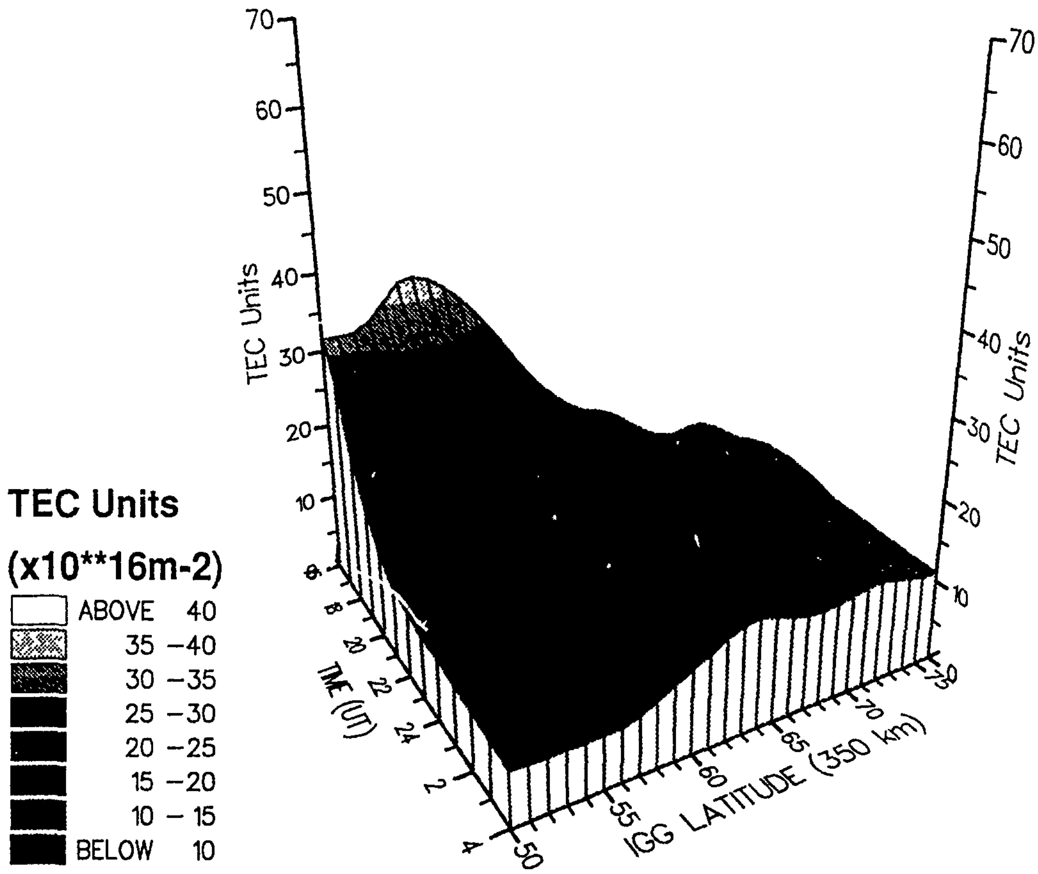

Fig.5

RESPONSE TO GEOMAGNETIC ACTIVITY

a) Low Kp

The two months of data under consideration encompassed a wide range of geomagnetic activity. Maps similar to those presented earlier were constructed to illustrate the variations of total electron content as functions of latitude and time during periods of low, moderate and high Kp. Figures 6 to 8 are maps showing observations recorded between 1600 UT and 0400 UT on the nights of 13-14 October, 14-15 October and 10-11 December 1989 respectively. At no stage during these observations was Kp above 1 for any three-hour period, so the behaviour is illustrative of very quiet geomagnetic conditions. The trough is not well defined in these three examples, though there is some evidence for a weak minimum to develop as the night progresses. The gradients associated with the feature are shallow, though a steady rise in the poleward wall after midnight can be seen in two of the examples. The lower electron content values and earlier post-sunset decline to a winter night can be seen in the December data. A broad, poorly-defined trough is clearly characteristic of very quiet geomagnetic conditions.

b) Moderate Kp

Two plots are included representative of conditions for moderate geomagnetic activity (Figures 9 and 10). On both nights Kp maximised at a value of 3. Both show a weak trough-like feature in the pre-midnight sector. However, in the early morning hours a more pronounced trough with a minimum near 60°N latitude can be seen. A feature in this time period is that the poleward wall rises steeply to reach a plateau or even a maximum at about 65°N. This type of structure seems characteristic of moderate levels of geomagnetic activity in the current data set, with some evidence of another weaker trough at higher latitudes in the post-midnight period. Fig.3 is another example of this kind of behaviour, the Kp index maximising at 2+ in that case.

c) High Kp

Fig.11 shows the observations made on the 22-23 September 1989 between 1600 UT and 0400 UT. A trough-like feature is clearly present, though shifted south in latitude compared to the

13-14 OCT 1989

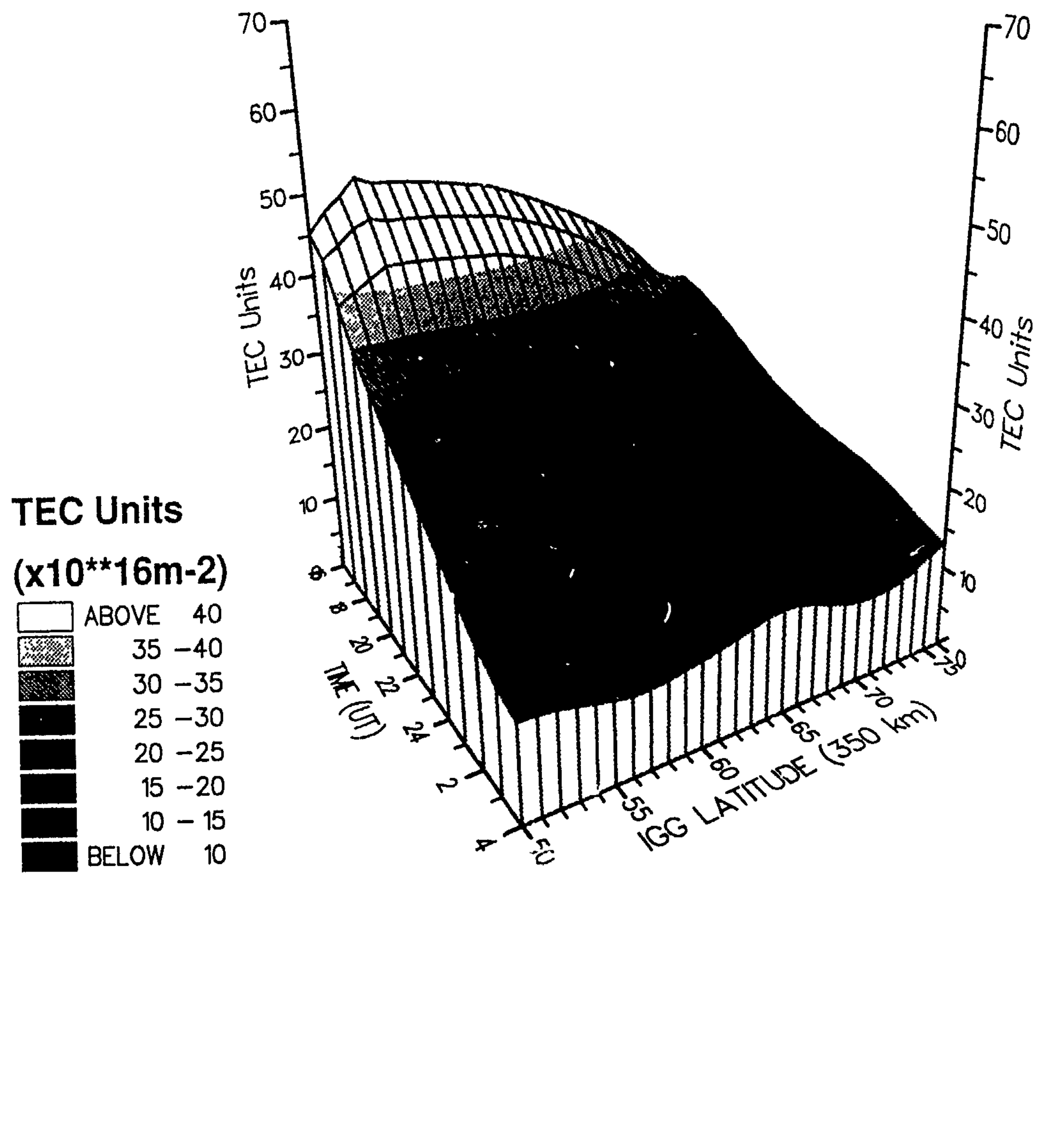

Fig.6

14-15 OCT 1989

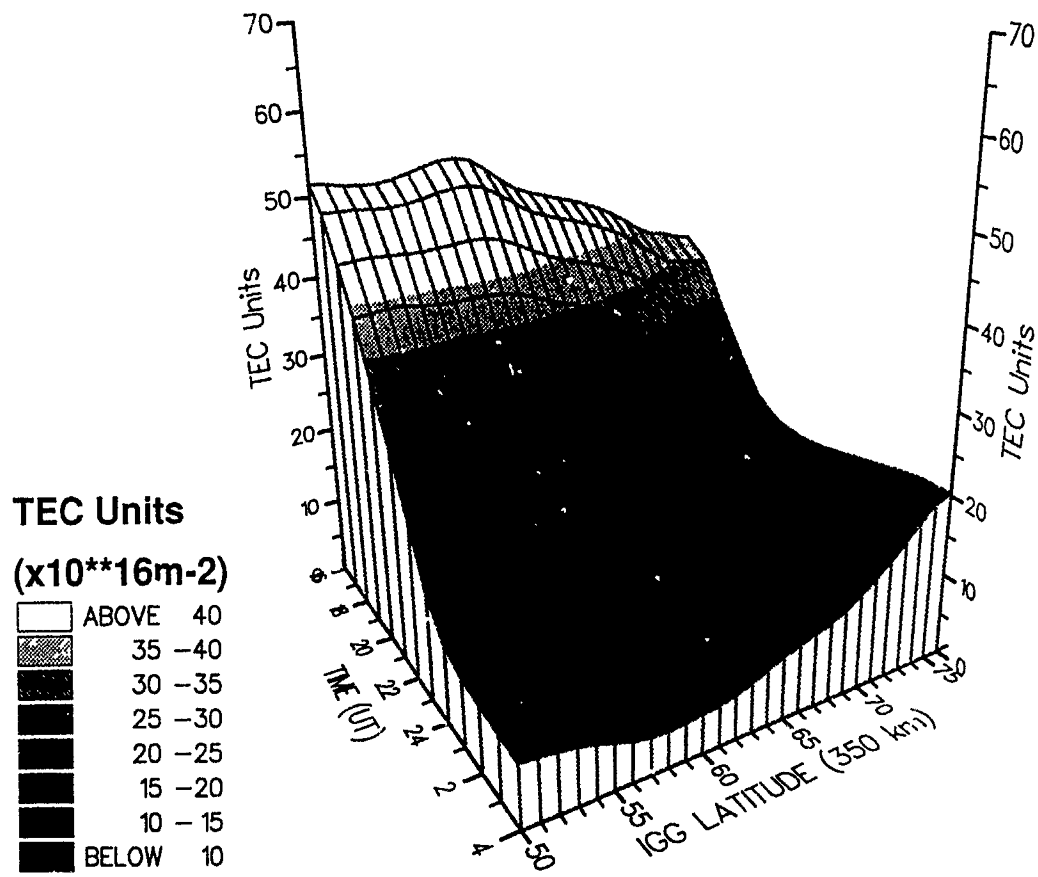

Fig.7

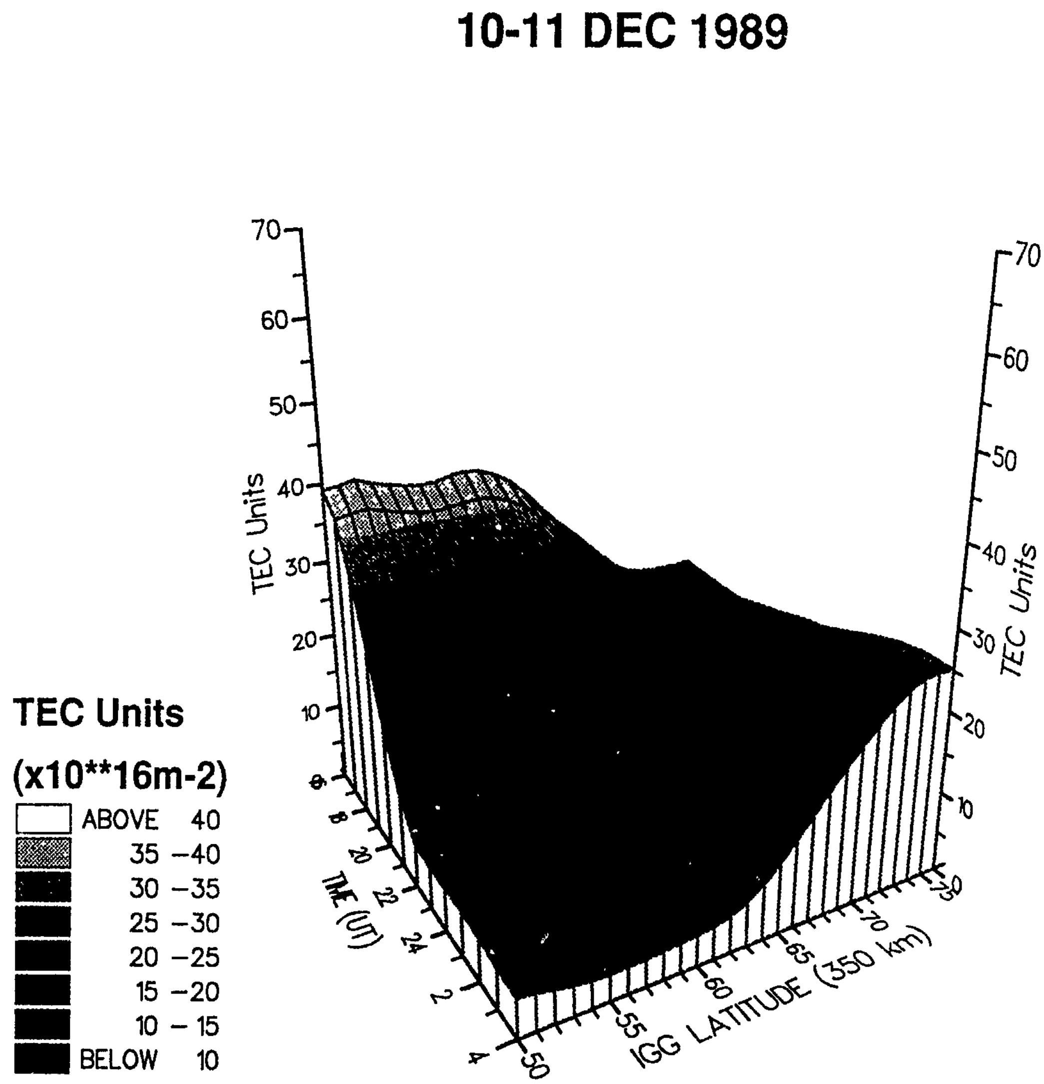
10-11 DEC 1989
TEC Units
(x10**16m-2)
ABOVE 40
35 -40
30 -35
25 -30
20 -25
15 -20
10 - 15
BELOW 10
TEC Units
TIME (UT)
IGG LATITUDE (350 km)

Fig.8

29-30 SEPT 1989

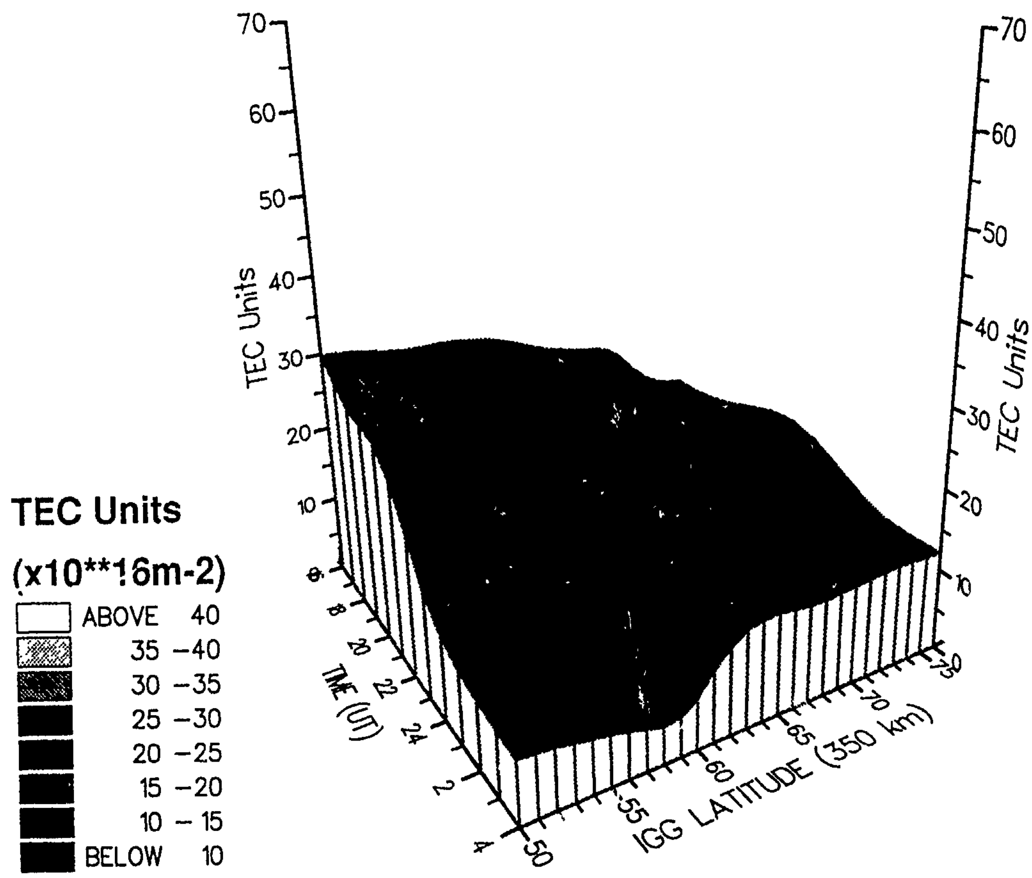

Fig.9

19-20 OCT 1989

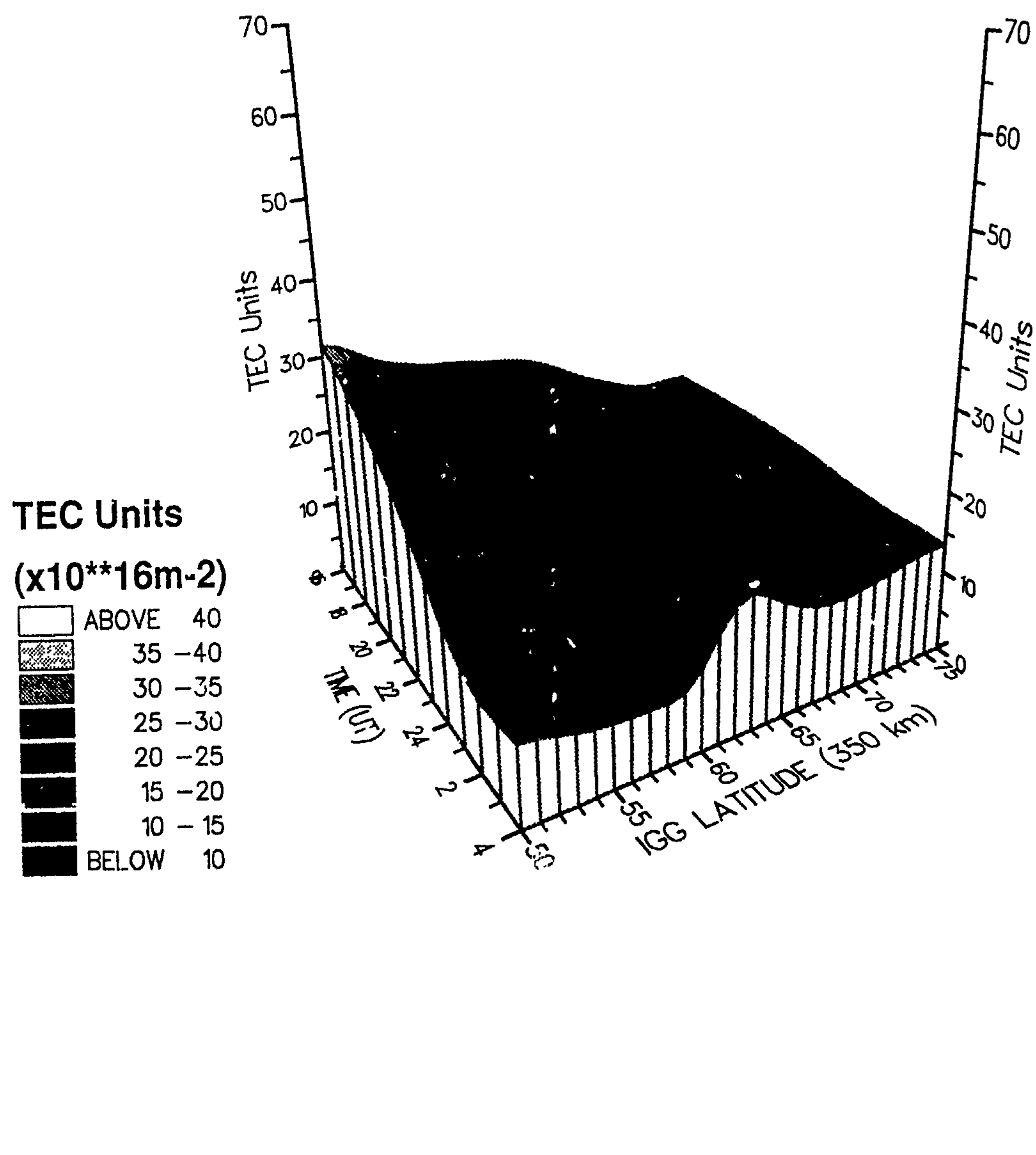

Fig.10

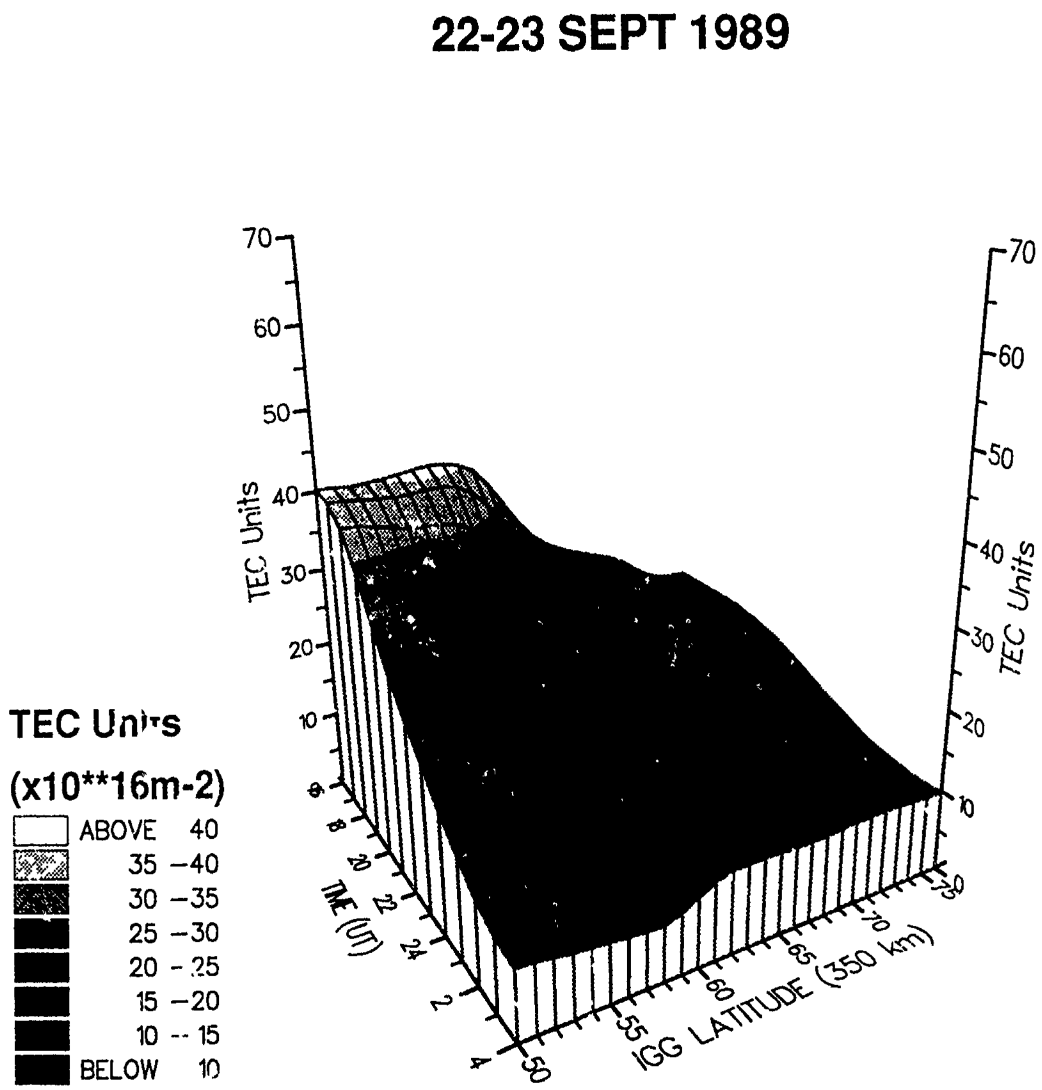
22-23 SEPT 1989
TEC Units
(x10**16m-2)
ABOVE 40
35 –40
30 –35
25 –30
20 – 25
15 –20
10 – 15
BELOW 10
TEC Units
TEC Units
TIME (UT)
IGG LATITUDE (350 km)

Fig.11

examples of troughs presented earlier in Figs.2 and 3. If direct comparisons are made at 2100 UT it can be seen that on the 22-23 September 1989 (Fig.11) the trough minimum is located at around 59°N, compared to approximately 64°N on the 11-12 October 1989 (Fig.2) and about 63°N on the 4-5 October 1989 (Fig.3). It should be noted that whilst this example has been included under considerations of high Kp, geomagnetic activity was such that Kp was only above 4 for one three hour period between 1600 UT to 0400 UT. In this example the trough walls are steep in the pre-midnight sector resulting in a narrow depression in the electron content.

Caution must be exercised in trying to generalise about the total electron content behaviour during disturbed geomagnetic conditions. It is well established that low night-time contents are found after storm onsets. Fig.12 shows an example where Kp reaches 8+ and the levels of electron content are generally very low, though minimum values are reached well below 60°N latitude in the post-midnight sector.

S_4 INDEX AND THE SCINTILLATION BOUNDARY

A previous report (Kersley et al. 1989)[14] described how the current experiment provides information on the scintillation of signals resulting from small-scale irregularities in electron density along the propagation path. A plot of the S_4 scintillation index for amplitude scintillation of the 150 MHz signal measured during a single pass is shown as a function of latitude in Fig.13. The pass was recorded on 14 October 1989 at around 1913 UT. A clear increase in signal fluctuation towards the north is seen, with the S_4 value rising from 0.2 (weak scintillation) at around 61°N to 0.7 (strong scintillation) near 69°N. This type of plot is typical of the passage of the ray path across the scintillation boundary.

It is possible to use a graphical technique, similar to that described above, to produce maps of the S_4 index as functions of both latitude and time. An example of such a map is shown in Fig.14.

This map corresponds to an identical time period and latitude range to that presented in Fig. 2.

---

14. Kersley L., Pryse S.E. and Russell C.D. Amplitude and phase scintillation and ionospheric irregularities at sub-auroral latitudes. Report AFOSR-87-0378, University College of Wales, March 1989.

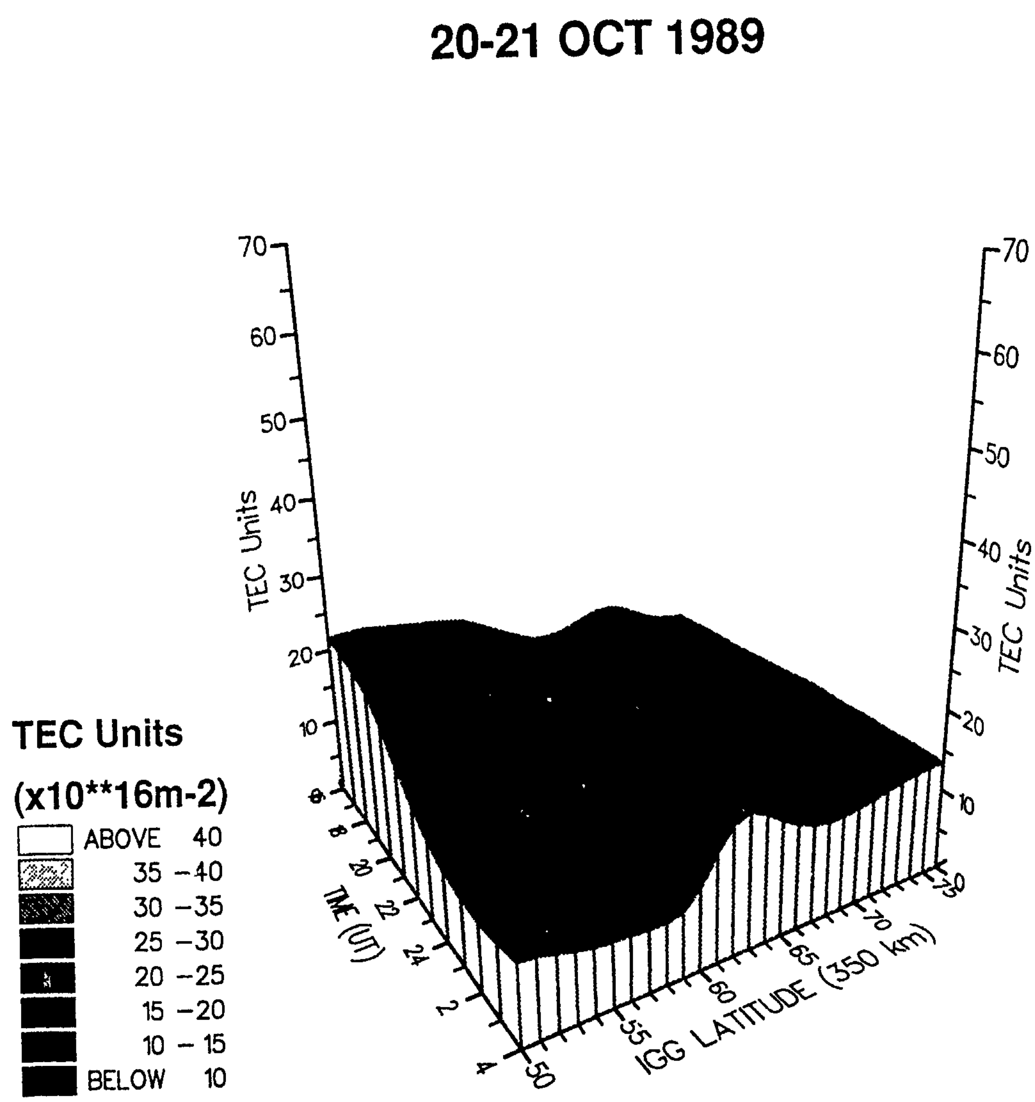
20-21 OCT 1989
TEC Units
(x10**16m-2)
ABOVE 40
35 -40
30 -35
25 -30
20 -25
15 -20
10 - 15
BELOW 10
TEC Units
TIME (UT)
IGG LATITUDE (350 km)

Fig.12

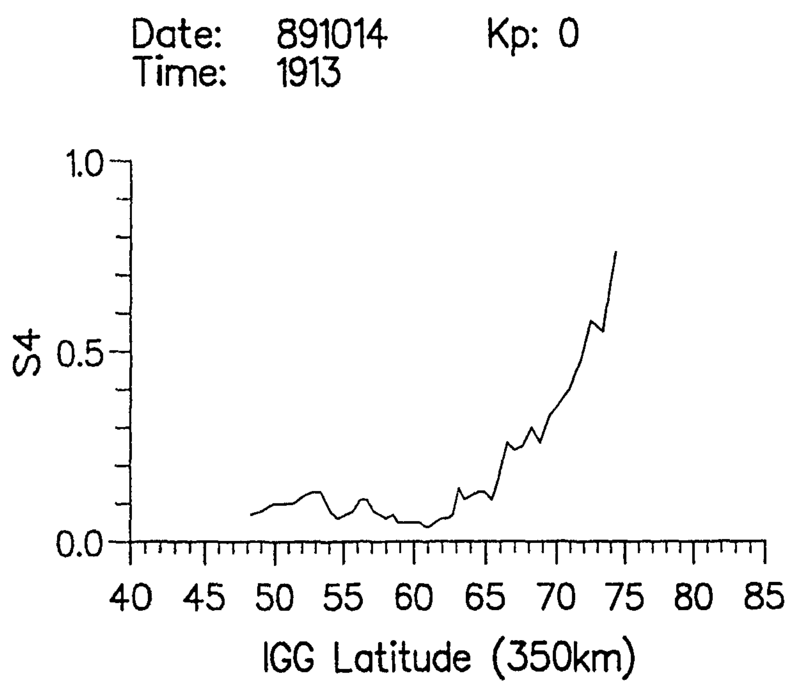
Date: 891014 Kp: 0
Time: 1913
1.0
S4
0.5
0.0
40 45 50 55 60 65 70 75 80 85
IGG Latitude (350km)

Fig.13

11–12 OCT 1989

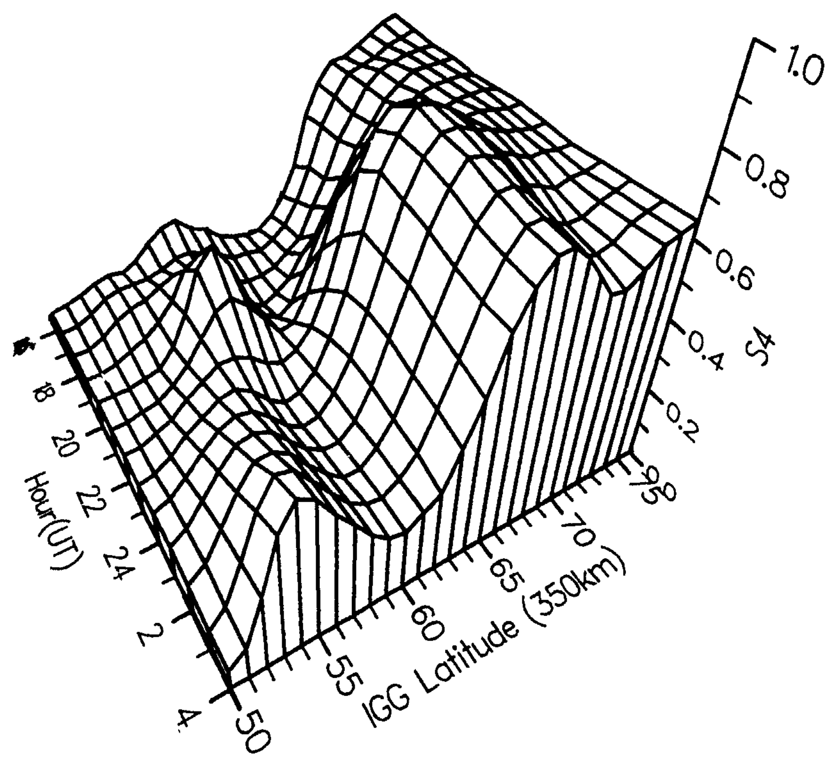

Fig.14

The dominant feature of this presentation is the sharp rise in scintillation towards the north associated with the scintillation boundary. It is sustained throughout the entire period shown here, but moving equatorward in the pre-midnight sector, most sharply around 2000 UT. It should be noted that some of the isolated structures observed south of the monitoring station at 60.1°N may arise at least partially from effects of the observational geometry. Due to the field-aligned nature of the irregularities an enhancement is seen in S_4 when the propagation path lies along a magnetic field line or is confined to an L-shell. A discussion of the observational effects appropriate to observations from Lerwick has been provided by Kersley et al. (1989)[14].

It is possible to combine the total electron content and S_4 data to produce a 4-dimensional map of the kind shown in Fig.15. The total electron content is represented by the wire-grid 3-dimensional model and S_4 by the superposed shaded contouring. It can be seen that, for this particular example, the steep rise in the S_4 scintillation index observed at higher latitudes appears coincident with the poleward wall of the trough and that the latitude variation of the boundary essentially mirrors the movement of the trough. This type of observation is of importance to understanding the nature of the physical mechanisms responsible for the production and growth of the small-scale irregularities causing the scintillation. It would appear that in the example shown here the irregularities are associated with gradients in electron content increasing towards the north, suggesting that the plasma convection in this case may have resulted in destabilisation. The strongest scintillation around 2200 UT is associated with the steepest northward gradient. A close examination of the region where scintillation was found to the south of the observing station shows that here again there is evidence that this is associated with a weak northwards gradient from about 2000 UT. These results appear to suggest that the gradient drift mechanism may have been responsible for the irregularity development in this case with northwards gradients being unstable to the prevailing plasma motion.

CONCLUSIONS

The work presented in this report has demonstrated that total electron content and radio-wave scintillation behaviour in the vicinity of the midlatitude trough over northern Europe can be mapped using the techniques described. The experimental observations made at Lerwick of

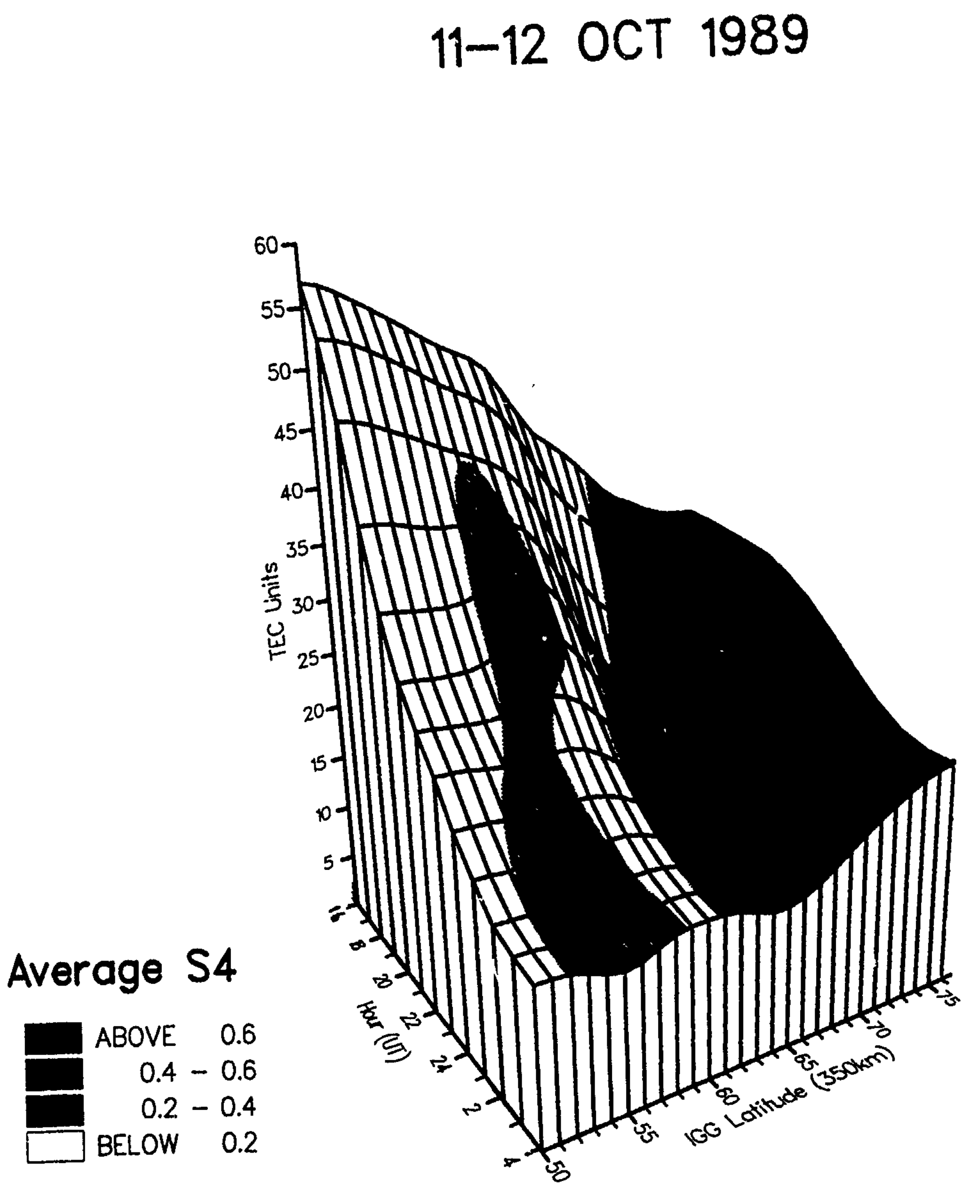
11–12 OCT 1989
TEC Units
60
55
50
45
40
35
30
25
20
15
10
5
Hour (UT)
16
18
20
22
24
2
4
IGG Latitude (350km)
50
55
60
65
70
75
Average S4
ABOVE 0.6
0.4 – 0.6
0.2 – 0.4
BELOW 0.2

Fig.15

transmissions from NNSS satellites, when calibrated with GPS measurements from a co-located receiver, have been used to study both electron content and scintillation as functions of both latitude and time and the potential of the technique has been demonstrated. The report gives examples of the night-time electron content during the two months when GPS calibration data have been available to date. Equatorward motion of the trough minimum and a steepening of the gradients in response to geomagnetic activity have been noted. A new feature of the work is the limited extent of the poleward wall of the trough under conditions of moderate geomagnetic activity. An example has been shown where the scintillation-producing irregularities are closely associated with northwards rising gradients in electron content. This demonstrates the potential of the technique for the study of small-scale structures. While it is not possible to reach general conclusions from the limited data that have gone into the present study, the experimental NNSS observations at Lerwick have amassed a very large data base ready for analysis once independent calibration measurements become available.

ACKNOWLEDGEMENTS

Thanks are due to Mr. Greg Bishop of the Geophysical Laboratory for his continued interest in this project and for many useful discussions.